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A research on the use of energy resources in the Amazon

Fernando B. Matos [a], José R. Camacho [b,*], Pollyanna Rodrigues [b], Sebastião C. Guimarães Jr. [b]

[a] Instituto Federal de Educação, Ciência e Tecnologia Goiano Campus de Urutaí Rod. JK 330 Km 2,5 Faz. Palmital 75.790.000 Urutaí, GO, Brazil
[b] Universidade Federal de Uberlandia School of Electrical Engineering Rural Electricity and Energy Sources Laboratory CEP 38408-100, C.P. 593, Uberlândia, MG, Brazil

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A B S T R A C T

The Amazon is a large area of forest that shelters the largest biodiversity in the planet. Although a region of richness in energy resources, around 40% of local residents do not have access to an electrical network, and the other 60% are connected to the largest islanded system in the world, supplied mainly by thermoelectricity running on diesel engines, spread for hundreds of communities, distributed along river banks, and inside thickest rain forest in the world. This situation does not allow the implantation of enterprises and industry, and mainly the development of resident communities inside the forest what relegates the population to a situation of low social and economical development, giving space to a predatory exploitation of natural resources, risking the environment where they are inserted. The use of alternative energy sources to substitute diesel oil or for its complementation start from the knowledge of available resources for the use of solar energy in the region, allied to the natural resources available with the use of biomass and natural gas and hydraulic resources that are abundant in the region.

Contents

1. Introduction

The Amazon is located in the center-north portion of the South-American continent where it is sliced by the line of Equator and, therefore, comprised by low latitudes and covering around 2/5 of the continent. In Brazil covers a total area of 3581 million of km^2 which is equivalent to around 42% of Brazilian territory, but shelters only 3% of the country inhabitants with approximately 5 million human beings.

Beyond Brazil, the Amazon Forest vegetation can be found in another 8 countries (Bolivia, Colombia, Ecuador, Guyana, French Guyana, Peru, Republic of Suriname, and Venezuela). The so called Legal Amazon is even bigger, covering 60% of the Brazilian territory in a total of 5 million km^2. It comprises the States of Amazonas, Acre, Amapá, and west of Maranhão, Mato Grosso, Rondônia, Pará, Roraima and Tocantins [1].

A very distinctive characteristic of the Amazon Basin is the fact of being one of the rainiest places on earth, with pluviometric index of more than 2000 mm a year, may reach 10,000 mm in some regions. During the raining season, from December onwards, water on rivers and river banks can rise 10 m, and may reach 18 m in some areas. This means that during half of the time, large portion of the Amazonian plains are underwater, characterizing the largest area of flooded forest in the planet, covering a region of 700,000 km^2.

This pluviometric density is a factor that makes more difficult the implantation of solar energy in large scale in the riverbank com-

* Corresponding author. Tel.: +55.34.3239.4734; fax: +55.34.3239.4704.
E-mail addresses: nando.cefet@gmail.com (F.B. Matos), jrcamacho@ufu.br (J.R. Camacho).

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munities, according to [2], the region has a large cloud coverage due to the high indices of air relative humidity present in the atmosphere, varying between 89% and 91% of annual average. Those values are obtained mainly due to the fact that the forest interacts with a significative amount in the climate of the region. The Amazon climate is equatorial, hot and wet, with a small temperature change along the year, around 26–32 °C.

According to [2], the Amazon region gets lower incidence of solar radiation during summer, despite the fact that is located close to the Equator line. During the winter months, the inverse occurs and the Amazonian region receives the largest global solar radiation [20,23]. This is due to the climatic characteristics in the Amazon region that presents a large fraction of cloud coverage and high precipitation during summer due to the strong influence of the Intertropical Convergence Zone (ITCZ), that is a belt of low pressure girdling Earth at the Equator. It is formed by the vertical ascent of warm, moist air from the latitudes above and below the Equator. The ITCZ has large influence on the climate of whole South-American continent, influenced mainly by agricultural and livestock production in many countries.

The main river in the Amazon Forest is the Amazonas river. The Amazonas river begins in Peru, at the confluence of rivers *Ucayali* and *Marañon*, enters in Brazil with the name of Solimões and is called Amazonas when receives the waters of the Negro river, close to the city of Manaus, in the Amazonas State. During the rainy season, the river can raise 16 m above the ordinary level and floods vast stretches of the plains, dragging land and parts of the forest. Their average width is 12 km, reaching frequently more than 60 km during the raining season. The flooded areas affected by the watery network of Amazonas River, forming a flood basin much larger than many countries of Europe together.

The Amazon river has more than 1000 tributaries has the largest output, is the widest river in the world, and is the main responsible by the development in the Amazon forest and the main means of transport of the resident communities in the region. The volume of their waters represents 20% of all the water present in the rivers of the planet. Has extension of 6400 km, flow of 190,000 m^3/s (16 times higher than that of the river Nile). At the estuary, where disgorge in the Atlantic Ocean, its width is 320 km, and presents average depth of 30–40 m. The region of the Amazon forest concentrated 70% of the Brazilian hydroelectric potential according studies of the Brazilian Ministry of Mines and Energy.

The region has an infinity of riches of wild fauna and flora, with an ecosystem which houses the greatest biodiversity of the world and broadly rich in iron ore, natural gas, and wood among other natural resources. Still more than 40% of the population resident in the Amazon region is below the poverty line, according to the IBGE (Brazilian Institute of Geography and Statistics).

This contrast is due to historical, geographical and regional factors, but one which is certainly a decisive influence is that 46.6% of the population of the state has no access to electricity network in their homes and/or communities. And that these persons are relegated to live in an era of pre-development, increasing its dependence on industrialized markets for the acquisition of goods and services, making difficult and even impossible the application of production techniques, food and products conservation, and mainly not allowing the implantation of any manufacturing industry or natural resources processing present in the region. Reducing population income and relegating them often to a subsistence economy, based on barter of goods and primary products, with no access to any type of social services made available by official institutions of the government or by the private network in its communities.

The great majority of the municipalities of the interior of the State of Amazonas have particular features as the municipality of Coari. The municipality of Coari, object of the study, has a population of about 85,000 inhabitants, and that approximately 50,000 live in the metropolitan center and 35,000 are spread among the 85 riverside communities belonging to the municipality. The municipality of Coari situated at 4° 5′ 05.57″ south latitude and 63° 8′ 30.17″ longitude to the west of Greenwich, at an altitude 40 m above sea level.

The city is supplied by a diesel thermal electric generator group with an installed capacity of 10,630 kW, nine generation units, 1 × 630 kW, 3 × 800 kW, 1 × 1100 kW, 2 × 1250 kW and 2 × 2000 kW [3] with a monthly consumption of 40,000 L of diesel oil a day which is fuelled by rafts rising up the river Solimões each 30 days. In this process are released into the atmosphere approximately 20.5 ton of CO_2 [4] and large amount of SO_2 (sulfur dioxide) a day from the diesel oil that contribute to the formation of acid rain, elevation of local temperature, which affects the fauna and flora of the region.

2. Socio-economic situation of the Amazon region

The development of the Amazon region may be represented by FIRJAN Municipal Development Index (FMDI) which is a adequacy of the HDI (Human Development Index) to the reality of Brazilian municipalities, where are taken into consideration requirements and own characteristic properties of Brazil. The index is for the year 2006, because it uses only official data submitted by ministries of labor, education and health which creates a gap of 3 years [5].

The FMDI presents a methodology that consists in the observation of the development of Brazilian townships in an annual basis, with municipal emphasis and national scope, making it possible to compare its state of development with the other Brazilian municipalities. It is possible to supervise the human development, economic and social, presented by an annual series, with exclusive basis on official data supplied by the government.

The previously mentioned index considers, with equal weighting, the three main areas of human development, namely, *Employment & Income, Education and Health*. The reading of the results – by development areas or of the final index – is quite simple, ranging between 0 and 1, the closer to 1, the greater the level of development of the municipality according the following classifications:

- with FMDI between 0 and 0.4 are considered to be low stage of development;
- with FMDI between 0.4 and 0.6, regular development;
- with FMDI between 0.6 and 0.8, moderate development;
- with FMDI between 0.8 and 1.0, with high economic development.

The results presented by this index indicate the development of a state, its capital and their municipalities in relation to other units of the federation. The states which composed the region of the Amazon forest present a regular level of development as presented in Table 1, where the greatest development index was observed in their capitals [5].

Table 1
FMDI index of states of the Legal Amazon region and its capital cities.

State	Índex	Place	Capital	Índex	Place
Maranhão	0.5720	26	São Luiz	0.7675	15
Pará	0.5899	24	Belém	0.7575	18
Amapá	0.5923	23	Macapá	0.6890	27
Acre	0.5993	20	Rio Branco	0.7148	26
Amazonas	0.6101	19	Manaus	0.7429	22
Roraima	0.6302	18	Boa Vista	0.7477	20
Tocantins	0.6321	16	Palmas	0.7496	19
Rondônia	0.6336	15	Porto Velho	0.7290	25
Mato Grosso	0.6545	11	Cuiabá	0.7653	16

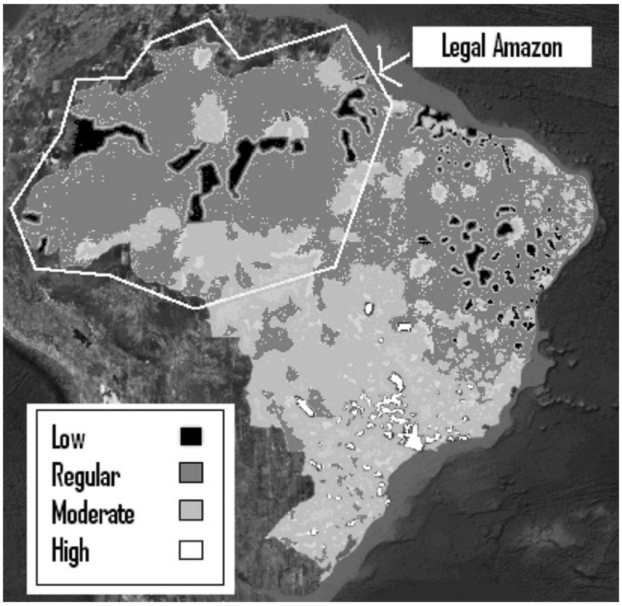

Fig. 1. Geo-referenced map of the FIRJAN index according the municipal development.

Making a comparison with the FMDI of S. Paulo State, the more developed state in the federation with the index of 0.8637, its capital (the city of Sao Paulo) with FMDI of 0.8568, second in the ranking among the 27 capitals and a national average index of 0.7376, highlights the lacking the region concerning the development of municipalities and communities which form the Amazon region, leaving them very close to states with lower development index that is Alagoas with FMDI of 0.5615 in the 27th place (Its capital city Maceió has FMDI of 0.7432 and occupies the 21st place.) [5].

The city of Coari has a FMDI of 0.5385. The index places the municipality as the 4th in the state of Amazonas in level of development and in 3743rd in the national ranking, however well below the state index and the national average representing the low index of development of cities in the Amazon region. In Fig. 1 is presented the country in a FMDI geo-referenced map.

This portrait of low development in the region of the Amazon Forest has as main characteristics the difficult access to local communities that predominantly is made by ship or aircraft and the trouble in the distribution of electric energy, that makes it difficult to access services and material goods, as well as the presence of the state in the region, so the access to daily basic services as health, education, public services among others turn to be considerably affected. Sustainable development is the subject of debate and discussion in social, governmental and academic circles [6] and is one of the greatest challenges for the Amazon [7–9].

This also explains the fact that the capital in such states has a FMDI index much higher than the state itself, because these urban centers concentrate most of the population (in the case of Manaus, concentrates around 50% of the State of Amazonas population), where energy systems are mostly interconnected to Brazilian energy system, something which does not happen with communities inside the state.

The economy of the communities in the interior of the Amazon forest is predominantly based on trade and the vegetable extractivism, applied on a flora with huge variety of species; hunting wild animals as the tracajá, jawbone and tapir; and fishing, where among thousands of valued species by local dwellers can be highlighted the tucunaré, tambaquí, pirarucú, pacú, piranha e bodó. In addition to the rubber tree and the caoutchouc, which draws rubber, are collected the Brazil nut, several types of wood, natural gums, guarana, babassu, mallow, açaí and many others. The mineral extractivism, gemstones and jewelry begins to assume greater importance, since the region has many resources, until today little explored, such as: gold in Pará, Amazonas, Roraima and Amapá; iron in Pará (Carajás mountain range, the world's largest), in Amapá and in Amazonas; rock-salt in Amazonas and in Pará; manganese in Amapá (Navio mountain range), in Pará and in Amazonas; bauxite in Pará (Oriximiná, in Trombetas river, and in Tucuruí), besides limestone, cassiterite, lignite, gypsum, copper, tin, lead, kaolin, diamond and nickel.

3. The Brazilian electrical system

Brazil is a developing country of the BRICs group (Brazil, Russia, India, and China) that has continental dimensions and which makes extensive use of energy resources to all sectors of modern society [10,11]. This means that there are thousands of kilometers of transmission lines, estimated at more than 80,000 km. According to the Ministry of Mines and Energy (2003), at the end of December 2003, Brazil had 1174 ventures of generation, totaling 81,286 MW of installed capacity, of which 96.8% were installed and connected to the national interconnected system and the residual 3.2% in isolated systems. From this total, 80.4% are from hydraulic sources, 14.75% thermal based on fossil fuels, 2.5% of are from thermonuclear plants, 2.3% thermal based on biomass and only 0.1% from wind energy. In addition to that own generation capacity, the import of electric energy was of a capacity of 8000 MW totaling an availability of 89,286 MW for the supply of the Brazilian electric energy market. Fig. 2a shows the distribution of Brazilian energy matrix and the Fig. 2b presents the matrix for electricity generation [2,12].

3.1. The State of Amazonas electric isolated system

According to the World Energy Assessment Report around 1.6 billion people around the world has no access to electricity [13,14], and the geographical issues and the large financial resources needed are responsible for the situation. In Brazil, there is an excellent scenario of abundance from different energy resources, and a wide network of generation, transmission and distribution which combined with a favorable economic situation of the country favors the broad universality of the resources serving approximately 96% of the Brazilian population, and then the geography of the Amazon region a great obstacle to the full interconnection of Brazilian energy system (Fig. 3).

The state of Amazonas is one of the five states which are covered by Amazon forest, this being the highest number of isolated systems. In the Amazon state there are 89 isolated systems, being the first serviced by Manaus Energia S. A., integral subsidiary of Eletronorte, and the other 88 with liability to Amazonas Energia S. A. – CEAM, distributed within the state.

The electrical system pertaining to Manaus Energy takes account of the state capital, Manaus, being responsible by the generation, transmission and distribution of electric energy, in addition to carry out the supply to three localities of the interior belonging to the CEAM system. The energy supply to the other isolated systems of the interior is the responsibility of CEAM, which takes into account through 88 sites of power generation.

Since 1997 Manaus Energia, through supply contract, acquire electric energy of the independent producer El Paso, to complement its own generation providing energy to the system. The Manaus Energia electrical system is responsible for servicing of 85.1% of electricity demand to the Amazonas state, while CEAM responds by 14.9% of the total requested. The installed capacity to care for the Manaus Energia system has 946 MW of effective capac-

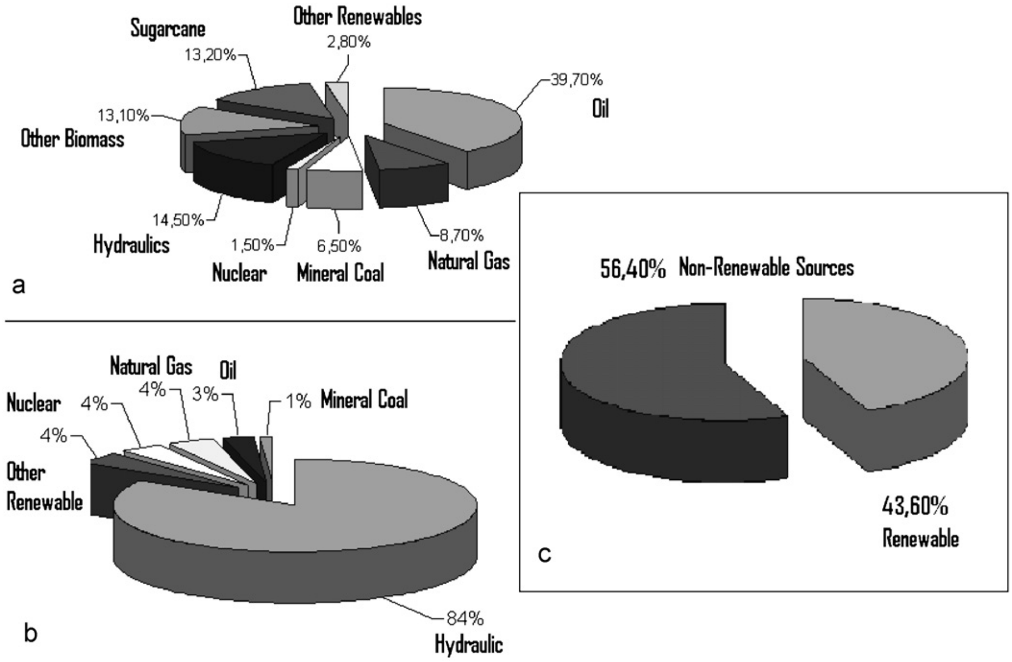

Fig. 2. (a) Composition of the Brazilian energy matrix. (b) Composition of the Brazilian energy matrix for electricity generation only. (c) Percent use of renewable energy sources.
Source: Brazilian Solar Energy Atlas.

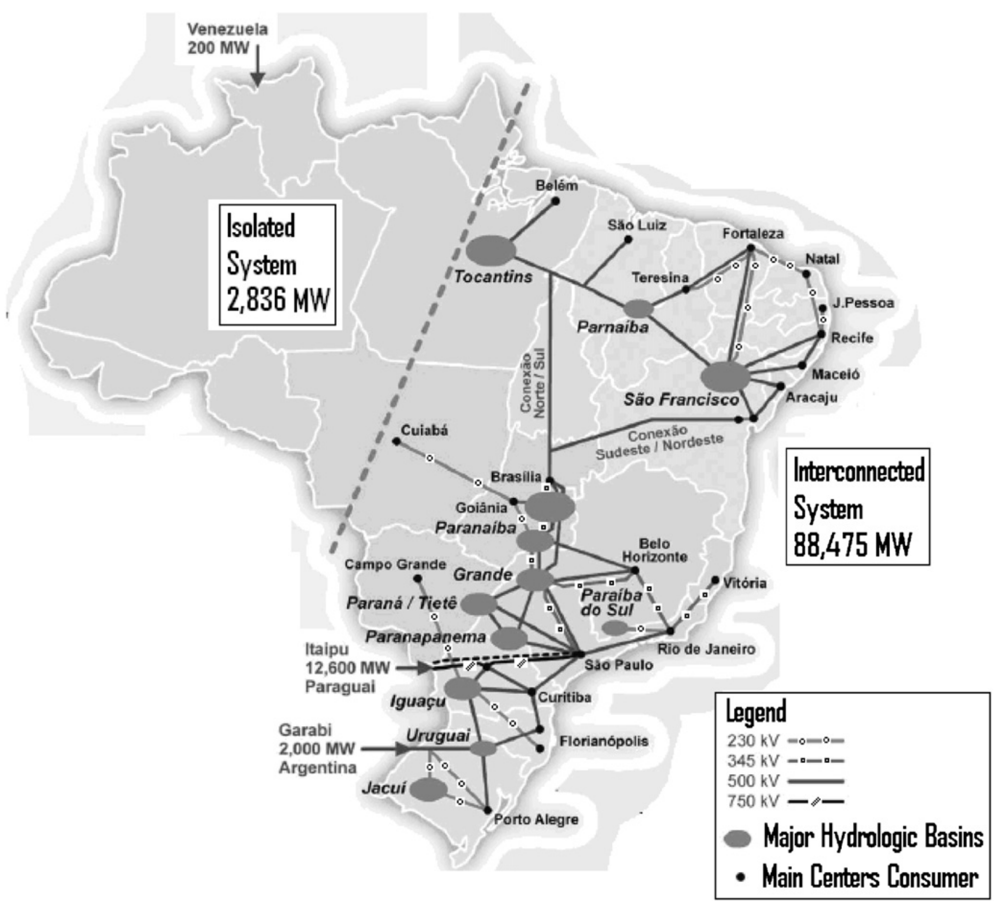

Fig. 3. The Brazilian energy system (interconnected and isolated).

Source: Brazilian Solar Energy Atlas.

Table 2
Installed capacity of isolated systems in the Amazon.

System	Generating units	Nominal power	Effective power
Manaus Energia	33	1063 MW	946.0 MW
CEAM	366	200 MW	160.6 MW
Total	399	1263 MW	1106.6 MW

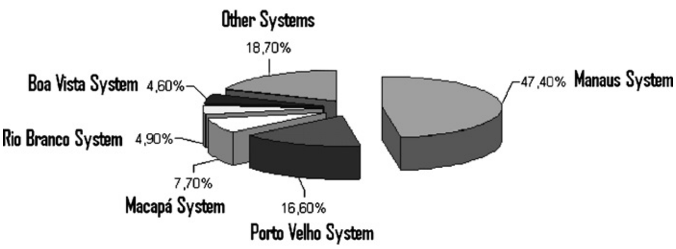

Fig. 4. Constitution of isolated systems in the Amazon.
Source: GTON—Isolated Systems Operation Planning.

ity; the effective capacity of CEAM is 160.6 MW as can be seen in Table 2.

This concentration is mainly by the fact of the city of Manaus hosting a tax free zone established by the federal government in 1967 where the main goal was to develop the region. So there was a migration to Manaus of various industries especially in the sector of technology, telephony, electro-electronics and motorcycles, highlighting Manaus as one of the principal poles of industrial production in Brazil. Thus only the Manaus Industrial District consumes more electricity than the whole of the interior of the state of Amazonas.

The isolated systems of all states of the Amazon region correspond with approximately 96% of all isolated systems existing in Brazil, where the systems in the state of Amazonas correspond to approximately 47.4% of total as can be observed in Fig. 4.

The electric systems of Manaus Energia and CEAM benefits a population of approximately 1.89 million inhabitants which is approximately 63.4% of the population of the state. The population still not attended by electric energy is very high, around 1.1 million inhabitants which corresponds to approximately 46.6% of the total, this being the largest number of Brazilians not attended by distribution services of electric energy [15].

Although the use of systems based on diesel generators presented as a solution to the Amazon region, it is only feasible due to the fact of recovery of the JCC-ISOl [12] and subsidies [25] of consumers of the interconnected system. Allied to that fact, the low efficiency of the system generates a service of low quality with constant blackouts and outside specifications, with variation higher than 50% in the value of nominal voltage with the occurrence of energy transients, which is the cause of burning of various apparatus and devices. The distribution of isolated systems in the Amazon can be seen in Fig. 5.

Among the factors that contribute to this situation are the great territorial extension of the state, the fact that the population is divided into small communities in locations with small sparse population density reaching values as 0.3 inhabitants per km^2 distributed along the riverbanks, flooded areas or even inside the thickest forest in the world what makes difficult the access and economically impossible to enlarge the electric network to take into account these communities. Also contributes to this situation the fact that the existence of a large number of units for the fauna and flora conservation, and the many indigenous reserves present in the state.

The Amazon is one of the few places of the planet where still be found primitive human people, dozens of tribes who spread in territories-inside the forest, maintaining its own customs, languages and cultures, unchanged for thousands of years. Anthropologists believe that there are still unknown primitive people living in the most inhospitable and inaccessible regions.

Thus the Amazon is the Brazilian state that presents the largest rate of need of electric energy. Experts agree that the difficulty to access to electric energy is one of the factors for the delay in the development of the region that is, since this resource becomes limited in communities inside de state, the development of industries and local trade is impaired, concentrating in the state capital all demand flow of goods and services required. This can be observed by indices for the development of states in the legal Amazon in accordance with the index FIRJAN and compared with other states of the federation [5]. This situation provides the indiscriminate exploitation of wild flora and fauna of the Amazon Forest, therefore jeopardizing thousands of species of all kinds for obtaining income by the population living there. Allied to this scenario, the lack of access to the formal education network and basic sanitation makes the population subject to various tropical diseases by parasites and worms which are already controlled and many extinct in other regions in Brazil.

4. Solar resources in the Amazon

The use of renewable resources such as solar energy is increasingly gaining space between the developed nations like the United States, Germany and Japan [16,17] has gained attention of countries with large availability of solar irradiation as in the Mediterranean region. In Brazil, its use is still incipient compared to other countries and the quantity of solar resource available [18,19]. It is also shown its little use, if taken into consideration that this is one of the main alternatives to be used in isolated communities of the Amazon forest.

The use of an area of 0.5% of the Bahia state, with power plants concentrating the solar heat will be enough to supply all the Brazilian energy demand. However one of the major difficulties to implement any type of policy towards the use of any alternative energy resource in the Amazon region is about the obtaining of reliable data concerning the solar intensity in the region, and the regime and constancy of winds. Simply because of the reduced number of stations for data collection present in the region, and the low demographic density associated to the great territorial extension, among others.

This panorama began to change when new models based on satellite images began to be used. Basically, there are two methods for the set up of resources of solar energy in a region large as the Amazon region: the use of a network of radiometers distributed in the region together with data interpolation techniques of radiation collected; and the use of computer models for the determination of estimates of incident solar radiation through empirical relationships or the solution of the irradiative transference equation.

Perez et al. [35] demonstrated that, when the distance between the radiometers of an observation network are greater than 45 km, the data interpolated for total daily irradiation presents reliability levels less than the estimates obtained with models using satellite pictures. Therefore for the characteristics of the Amazon region it is then suggested the use of the radiative transference equation.

To estimate the flow of solar radiation on the surface, models using parametrization that simulates physical processes in the atmosphere (in its various layers). The parametrization is based in data collected in a surface and/or by satellites which allow inference in the optical properties of the atmosphere and, therefore, the contribution of each radiative process in the total atmospheric transmittance for the solar radiation.

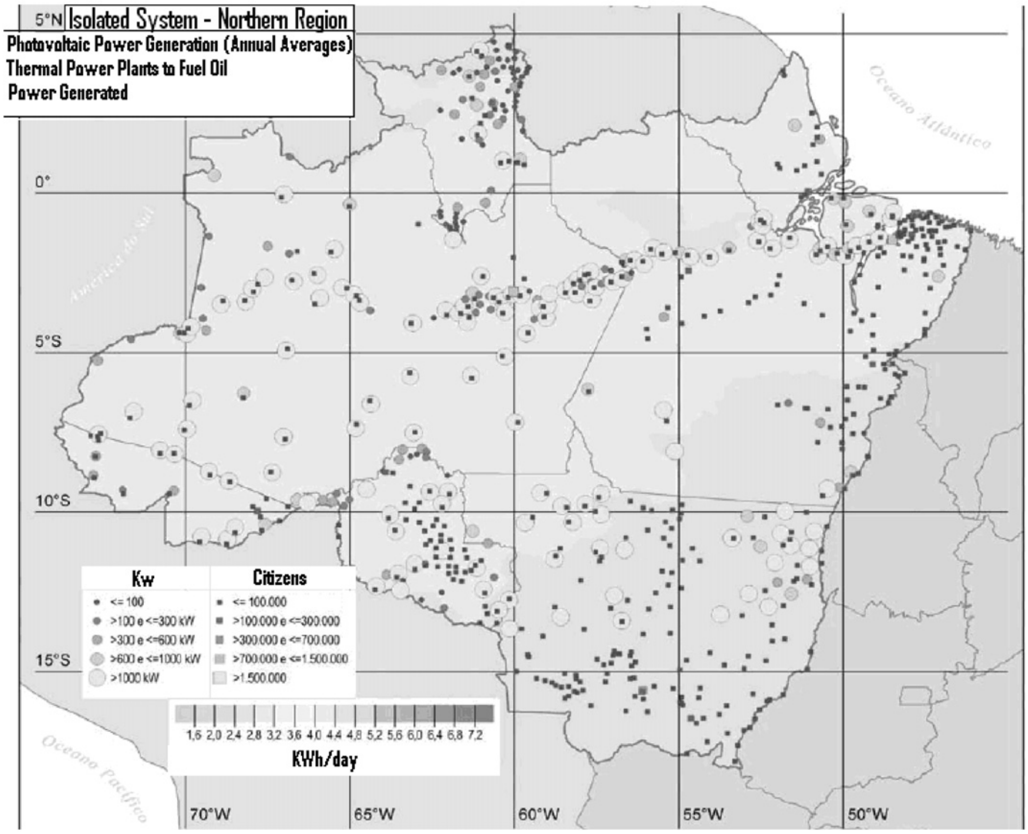

Fig. 5. Isolated systems kept by diesel generation in the Amazon.

Source: Brazilian Solar Energy Atlas.

The models used to describe the radiative transference may be based on statistical data which use empirical formulations between measures for incident radiation on the surface and local weather conditions and, generally, have restricted validity to the studied region. Then the physical models are valid for any region since they solve the radiative transference equation that describes mathematically physical processes occurring in the atmosphere [2,21,22].

The model used in the Atlas is the BRASIL-SR, which is a physical model for obtaining estimates of incident solar radiation on the surface from climatic information and parameters determined from satellite pictures. The data presents average values of estimates of the total daily solar irradiation provided by the model of radiative transference BRASIL-SR for the period of July 1995 to December 2005 as part of the SWERA (Solar and Wind Energy Resource Assessment) project coordinated by CPTEC/INPE under te sponsorship of the UNEP (United Nations Environment Program) and GEF (Global Environment Facilities).

The data shows that with the average annual, may be observed that the Northern region of the country is that presents the highest levels of diffuse radiation, mainly on the mouth of the Amazonas river. This is due to the largest haziness in the region as a result of ICZ (Intertropical Convergence Zone). Seasonally, the higher levels of diffuse radiation occur during the summer on all the Amazon region and the lowest indexes occur during the winter on the southeastern and southern regions in the country [21].

According to [2] the global solar horizontal radiation atlas the daily annual average for the Amazon region is between 4.55 kWh/m^2 and 4.90 kWh/m^2. It is also possible to observe the distribution of global solar horizontal average according to the season. Table 3 shows the distribution of solar radiation in the Amazon.

The solar radiation in the spectral zone photosynthetically active daily annual average for the Amazon region is in the range of 2.15–2.45 kWh/m^2. These data may be seen according to the season through Table 4.

Table 3
Distribution of global solar horizontal radiation daily average according to the season.

Season	Months	Daily average (kWh/m^2)
Summer	December, January and February	4.90–5.60
Autumn	March, April and May	4.20–4.55
Winter	June, July and August	4.55–5.25
Spring	September, October and November	5.25–5.95

The solar radiation in the spectral zone photosynthetically active is a relevant data when the focus of electricity generation is directed to the processing of biomass from resources generated by agribusiness. In the case of the Amazon region, the native development of oleaginous plants with potential to be used in the production of biodiesel is a relevant factor.

The daily annual average solar radiation in an inclined plane is between 4.60 kWh/m^2 and 5.60 kWh/m^2. This data is seasonally distributed as can be seen in Table 5.

Radiation in the inclined plane indicates the better use of solar energy for photovoltaic systems with the inclined plane at the same degree of latitude corresponding to their location on the

Table 4
Solar radiation in the spectral zone photosynthetically active daily annual average according to the season.

Season	Months	Daily average (kWh/m^2)
Summer	December, January and February	1.85–2.30
Autumn	March, April and May	1.70–2.00
Winter	June, July and August	1.70–2.00
Spring	September, October and November	2.15–2.60

Table 5
Daily annual average solar radiation in an inclined plane.

Season	Months	Daily annual average (kWh/m^2)
Summer	December, January and February	4.60–5.60
Autumn	March, April and May	4.60–5.60
Winter	June, July and August	4.40–5.00
Spring	September, October and November	5.20–6.00

Table 6
Daily annual average of diffuse solar radiation.

Season	Months	Daily annual average (kWh/m^2)
Summer	December, January and February	2.20–2.50
Autumn	March, April and May	2.20–2.35
Winter	June, July and August	1.60–2.05
Spring	September, October and November	1.90–2.05

ground (ignoring in this aspect the characteristics of the ground surface).

The daily annual average of diffuse solar radiation is in the range of 2.05–2.50 kWh/m^2. Table 6 shows the variation along the whole year in each season.

The Amazon region presents a great constancy in lighting conditions to which is the subject, a variation of annual average is less than 25%. Its climatic characteristics that reduce the variability of solar irradiation incident in surface influenced mainly by ITCZ that causes in the region continuously a large percentage of haziness [22].

In the same way, the region presents the lowest variability during the winter where it is rare the occurrence of rain in the whole region and the number of days with cloudlessness is greater, reducing the variability of solar irradiation. The greatest variability of solar radiation is observed during the summer, when the rains are more constant, favoring the presence of a larger haziness during that period [21,22].

These data is important for the simulation and dimensioning of thermal and photovoltaic systems for the implementation in communities situated in the region of the Amazon Forest [24,25].

5. The use of biomass

With reduced cost of operation and maintenance, biomass gasifiers producing energy from typical rejects of agro industrial waste of the Amazon region, such as cocoa husks and cupuaçu and açaí kernels, piquiá, babassu, bacuri and tucumã, which are resources abundant in the Northern Region. The industrial process may use solar dryers [26,27] and husks, kernels and plant residue is burned inside the gasifier with little oxygen. The incomplete combustion produces a synthesis gas with enough calorific power to feed engines and to produce electricity.

Various programs such as Enerbio, from UFPA (Universidade Federal do Pará) is sponsoring research on sustainable development of communities of the interior of the Amazon forest through the generation of electric energy using biomass resources, in particular the seed of açaí, the use of biomass decrease the dependence on fossil fuels [25].

The communities that have isolated systems of electricity generation are using diesel oil engines. In addition to be a highly polluting source of energy, the cost of transport of fuel makes its use very expensive. The federal government by means of a decree created in 1973 the Fuel Consumption Account for Isolated Systems (CCC-ISOL), in which prorated 75% of the cost of fuel and of its transport to the generating plants serving the remaining of consumers that are part of the national interconnected electrical system. This mechanism has enabled the implantation of various isolated systems in the communities of the most remote areas, which would be impossible if the fuel cost would be charged only to the communities attended by isolated systems. THE CCC-ISOL has its final year of operation in 2022 [12].

The use of gas resulting from the process of gasification may be used in diesel or petrol, contributing to the reduction of about 80% of the use of diesel and 100% of petrol consumed by the engine, significantly reducing the value of electric energy for all Brazilian consumers.

The use of resources from biomass starts from the identification of the ideal product to be exploited, must-establish the best method for the cultivation, harvest, storage and the conversion into energy. It is necessary that the people of the community are trained to operate and make small maintenances in the system, as well as to manage independently and continuing the project after the implantation. Such care should be taken by the fact that transport, logistics and the huge distances found in the region of forest are inherent obstacles to the conclusion and the maintenance of any project.

Other form of use of biomass is through the biodiesel, obtained from palm oil and babaçu oil, as an additive or supplement in internal combustion engines, generator groups or thermoelectric plants powered by diesel or automotive oil, used for the generation of energy in isolated communities of the Amazon. The engine performance was satisfactory when the biodiesel was mixed with diesel oil in the proportion of 25% and 75%, respectively. The fleet of vehicles powered by diesel engines in Brazil already uses a fuel that has in its composition 5% of biodiesel.

The use of alternative fuel can also contribute to fix the man in the field, strengthening the regional agricultural economy [28] and working for the preservation of native species of the Amazon region. The need to produce biodiesel will result in the generation of jobs and income in the communities, in addition to reduce the demand for diesel and promote a source of less polluting energy.

6. The use of natural gas

In 2006 was inaugurated the construction of the Urucú-Coari-Manaus pipeline, which is one of the greatest ventures for the transport of natural gas in the country whose the operation started in November 2009. The pipeline is the means for a significant change in the energy matrix of Amazonas State to enable the gradual replacement of diesel oil and fuel oil of thermoelectric plants used in supplying the metropolitan region of Manaus-AM on natural gas for electricity generation [29].

The first unity to receive the natural gas was the Petrobras Refinery Isaac Sabbá (Reman), with an initial consumption of 77,000 m^3/day. In 2010, the consumption was around 253,000 m^3/day. The pipeline Urucu-Coari-Manaus was the pipeline work in the country with higher percentage of use of local workmanship: 70%. Approximately 8.9 thousand workers worked directly in the construction and other indirect 26.7 thousand jobs have been generated from the work. Considering all the workers involved in the venture, 8.7% were women (774). Taking into account all the material used in the work, 95% was produced in Brazil. In relation to machinery and equipment, the percentage was 85%.

The pipeline has initial capacity to carry 4.1 million m^3/day and is provided for the installation of two intermediate compression stations between Urucú and Coari what will increase the capacity of the pipeline to 5.5 million m^3/day, and may reach 10 million m^3/day. The pipeline Urucú-Coari-Manaus allows the delivery to the market the gas produced in the Solimões Basin, the second largest reserve of the country, estimated at 52.8 billion m^3, behind only of Rio de Janeiro (144.8 billion m^3). Although this extraordinary reservation were already known to many years,

Fig. 6. Pictures of the construction of gas pipeline Urucu-Coari-Manaus. (a) Aerial view of opened channel for the passing of the gas pipeline. (b) Installation of pipes in the forest. (c) Back-earthmover bogged in construction works. (d) Welding the gas pipeline and diagnosis through ultra sound and X-rays to check for leaks and welding failure.

problems relating to logistics in the transport of gas prevented the commercial exploitation, due to the unique characteristics of the Amazon forest.

In the face of natural conditions of the Amazon, Petrobrás, through its subsidiary, as well as the other pipelines under the operational responsibility of Transpetro, the pipeline Urucú-Coari-Manaus will be operated in remote and automated mode through the National Operational Control Center (CNCO), with headquarters in Rio de Janeiro-RJ.

The main trunk of the pipeline is of 661 km and has a branch of 140 km for servicing seven cities (Coari, Codajás, Anori, Anama, Caapiranga, Manacapuru and Iranduba) and the plants of Aparecida and Mauá in Manaus. The cost of venture is around US$ 2.6 billion [29].

In addition to the energy and environmental importance, the Urucu-Coari-Manaus also stands out by unprecedented engineering solutions adopted during the construction and which allowed the conclusion of the work in the shortest possible period of time, with respect to the environment, the pipeline required several technological innovations, in the face of the need for the installation of a pipe in the midst of the Amazon forest with the least possible environmental impact and to overcome differences in water levels that may reach 14 meters according to the season of the year, in addition to the conditions of an inaccessible wet and rainy region. To overcome these obstacles, Petrobras built the gas pipeline mainly in rivers to minimize the intervention in the environment, as presented in Fig. 6.

The thermal power plants of Tambaqui (60 MW), Manauara (60 MW), Jaraqui (60 MW), Aparecida (152 MW), Mauá (268 MW), Cristiano Rocha (65 MW) and Ponta Negra (60 MW) will use natural gas, replacing the diesel oil and fuel oil. Responsible for supplying the Amazonas state capital, together the plants have 725 MW of installed capacity.

To keep the supply of electricity in Manaus, the conversion of the plants for use with natural gas is being made gradually and must be completed until the end of 2010. As the plants are formed by a number of engines, the conversion is being made machine by machine, until all the generation park is able to operate with natural gas. The replacement will reduce around 30% of the emissions of carbon dioxide (CO_2) in Manaus, which corresponds to approximately 1.2 million tones of gaseous pollutants each year. This is a significant figure, because the generation of carbon dioxide by man is responsible for more than 50% of the gas being the cause of the greenhouse effect [30–32].

Despite the implantation of such branches to the pipeline backbone, only part of the population residing in the cities will enjoy this wealth, as approximately 40% of the population resides in riverside communities isolated from cities, what makes necessary the feasibility study and implantation of new forms of electricity generation. Furthermore, the lack of attention of federal, state and municipal governments is another obstacle for the full use of this resource. A proof of this statement is that even with a gas pipeline branch to the city of Coari, does not exist any prevision for the construction of a power plant running on natural gas in the region to provide electricity to a population of 50,000 inhabitants, this city will continue to have the service by extremely inefficient and expensive diesel generators with all the limitations already presented [33].

One of these possible forms for use of natural gas would be the association with the thermoelectric gas plant a solar thermal high temperature plant [30–32] for the use of energy resources of the

region, which could contribute to take account for the main cities in inner municipalities with greater efficiency.

7. Hydro energetic use in the Amazon

Despite the fact that the river basin at the Amazon forest is the largest in the world, with around 20% of the fresh water in the world with existence of thousands of rivers of any size, up to end of the seventies the rivers in the region were not thought as a source of energy. This because the rivers are situated in lowland, where waterfalls are rare, and the gap of their springs with the sea level is around only few hundred meters. Allied to this fact is the difficult to transmit this energy through the forest and its connection with the Interconnected National System (SIN).

With the shortage of embanked large rivers in Central-South of Brazil, the exploitation of rivers in the northern region (Amazon Forest) started to gain strategic importance. Recent studies made the Brazilian Ministry of Mines and Energy revealed an utilization potential of 70% of the Amazonian rivers to generate electricity.

A change in this scenario started from the construction of Jirau, Santo Antônio and Belo Monte hydro plants. The hydro plants of Jirau (3300 MW) e Santo Antônio (3150 MW) are both parts of the hydroelectric complex at Madeira River. The auction for the Santo Antônio power plant was already made and the consortium of undertakers to build it is already established in the region.

Both power plants will add to the Brazilian electric system 6450 MW, considerably increasing the domestic supply of electricity, so will be necessary a physical and geographic enlargement of the (SIN) National Interconnected System with the construction of new transmission lines, that will improve the national and regional distribution of electricity.

According Furnas, the state company responsible for the construction of the Madeira River system, the cost of building the power plants of Jirau and Santo Antônio will be around US$ 5 billion and will be commissioned in 2012 (first and second units in December 2012 and the last in June of 2016). The artificial lake to be formed will have 271 km^2, at the elevation of 70 m. From this total, only 40% correspond to new areas to be flooded; the largest part, 60% correspond to the Madeira river downspout in this stretch. Among new areas to be flooded and that necessary for the implantation of the construction site will be necessary to extract and use 15 km^2 of forest.

There is still an environmental and social compensation program, according to resolution of CONAMA (National Environmental Council) 371/2006, which corresponds to 1.0% of the venture value. This is US$ 50 million; split in half for the environmental and social programs, the social compensation program refers to a commitment of the consortium Furnas/CNO to be invested in the region.

The Belo Monte power plant will be built in the Xingú River, in the State of Pará and its installed capacity will be 11,233 MW, the largest hydro plant with a single owner, Itaipú Power Plant is located in the border between Brazil and Paraguay and is owned by both countries. The prevision is that when finished the power plant will be third largest hydro plant in the world, behind the Three Gorges (18,300 MW) in China and Itaipú (14,000 MW) in the Brazilian-Paraguayan border.

The estimated initial cost of Belo Monte is of US$ 40 by MWh, what could result in a total cost of US$ 11 billion. However a new government estimates raised the MWh cost to US$ 49, what left the final cost estimate close to US$ 20 billion. The private initiative however estimate that will be necessary US$ 30 billion to finish the venture. The design shows three independent machine houses and its lake will flood an area of 516 km^2. According preliminary studies, during the Amazon dry season, which occurs in the periods of August to November, the generating capacity of the Belo Monte Power Plant being will be limited to half of its capacity. This due to the fact that the employed technology in the design of the reservoir to make smaller the necessary lake for the operation of hydro plant and also to allow the passage of sediments, marked characteristic of rivers in the Amazon. So the time of water remaining in the reservoir is minimized, with 80% of fine sediments passing through the dam, being retained the heavier parts (heavy sand and gravel) according official theory in the project. The employment of this technology allowed that the Belo Monte reservoir to reduced to only 38% of the size of Itaipú that has 1350 km^2. This power plant has generated much environmental controversy due to the reallocation of indigenous people, its geographical location and the large seasonal water characteristics in this river making energy generation highly dependent of the raining season.

8. Future technologies

The Chemistry Institute at UNICAMP (Universidade de Campinas – Brazil) is developing a research on how certain group of metals acquires spontaneously electrical charge in conditions where the air relative humidity is higher than 50% [34]. Water present in the atmosphere acquires electrical charge when in contact with dispersed particles in the air, as silica and aluminum phosphate, transferring them this electrical charge. Whereas silica turns to be charged negatively, the aluminum phosphate is positively charged, absorbing ions from the atmosphere loaded with steam where are present a large concentration of ions $OH-$ and $H+$, in a transference process of the gas–solid interface, where is possible the generation of electric current. This process is called hygroscopic electricity, in other words, the electricity from air humidity.

The absorption of steam over isolating material surfaces or isolated metals in an armored and grounded medium (dielectrics), leads to the accumulation of electrical loads on the solid, with an intensity that depends on the relative humidity of the air, the nature of the surface and the time and exposition to the humidity conditions. So the high increase in the accumulation of electrical loads is obtained when liquid or insulating substrates are under the action of external fields with an air relative humidity near to 100% [34].

The Amazon region is an excellent place to the use of this type of technology, since the relative humidity average is always above 50% throughout the year, including the winter when is less rain in the region (average occurrence of one to two times a week), but still high for some regions in the country. This is due to the interaction of the climate with the forest with its innumerous rivers and flooded lowland that feed constantly with humidity to always keep it at this level.

Another technology that can be used to supply or at least to complement the use of non renewable energy sources as the diesel and natural gas is the use of solar energy to produce hydrogen from water hydrolysis. This hydrogen can be used in fuel cell technology power generation systems, where the main advantage is in the possibility of production being made close to the energy consumer center. This due to the fact that the logistics of transport for the diesel and natural gas is disturbed a lot due to extreme conditions inside the forest. Depending on the time of the year, in the period of receding rivers (from August to November), navigation becomes very difficult and riverbank communities and even small cities become completely isolated. The use of fuel cell technology allows not only the use of abundant resources in the region as the solar energy and the immense quantity of water for energy production, but also could allow the decrease in the pollution produced by non renewable energy sources in the region. The use of fuel cells fits perfectly in this scenario, since it allows the application of distributed generation concept that is a basic requisite for the energy demand of the population of the Amazon region.

9. Conclusions

The Amazon Forest region has a large diversity of energy sources that are possible to be used for the electrical power generation. However the lack of detailed studies that take in consideration the characteristic of the population, regional geography and climate are great obstacles to the broad universalization of this resource that is indispensable for the development of the communities inside the forest, they are more than 1.1 million people without access to electricity.

Allied to this fact, it is added the lack of government policies to this communities, what produces the migration for large centers and the predatory exploitation of natural resources for the local residents. This predatory action puts at risk both the fauna and flora of the region and impoverishes even more the population, this is a reflection of low rates of economic and social human development in the region.

Although the rivers in the region of the Amazon Forest have a great potential for the installation of hydro power plants, and this is the main option of the Brazilian government for energy generation due to the fact that the country has large engineering expertise in this technology and mainly the immediate generation of thousands of direct and indirect jobs for the construction of these generation plants, this solution apparently free of CO_2 emissions is environmentally dangerous for the local biodiversity. That solution puts at risk the existence of thousands of species, both animal and vegetable, and also the innumerous types of insects. This is the fact that the lake formed with the damming such river floods several areas slaughtering species which may not be transplanted to other locations, as colonies of ants and termites. The organic matter decomposing in the bottom of reservoirs composed mainly by dead forest also presents a potential source for the release of CO_2. Furthermore, the fact is that the formation of such artificial lakes changes the micro-climate of the region, changing the area environmental balance, and changing the behavior of certain types of plants, wild animals and mainly the fish.

Although a detailed study on the use of wind energy has not yet been carried out, their location in the area of the Amazon Forest is unlikely, due to the weak system of winds observed and also that the plant cover typical of the region presents trees with height varies from 50 to 70 m.

Another possible exploitation of natural resources of the Amazon region that needs research is the use of river running waters for the electricity generation in stationary barges equipped with electrical generators moved by the force of waters. This is possible since the region has many rivers with a large volume of water and with running waters at almost constant speed in any season, where many communities exists, this approach can make the distance smaller between the energy production point and the consumer. The modeling of water current on rivers could allow the elaboration of a map of eligible points of energy use in the river, and to build a set of better equipment to attend the demand without damaging navigation and fisheries that are both essential for the transport and survival of riverbank communities.

Thus a more viable alternative is the use of solar energy, both the photovoltaic and the thermal, to take account of isolated communities. The alternative mentioned although cannot alone respond by 100% of demand, may be used to complement other approaches used for electricity generation. The fact of solar energy is not ideal to supply that demand only, comes from the climate of the region, which has a sky with a great cloud cover, because there is the influence of the ITCZ, and a characteristic of intense rain in the summer. Furthermore, the fact that the mean ambient temperature remain above 30 °C makes this region a predominant user of air conditioning equipment by the community, making then necessary the use of other larger and more reliable energy source.

Although this is an inherent difficulty, the sparse distribution of the communities by the region of forest prevents the establishment of a distribution network, and then, it is necessary the distributed generation in each riverbank community, or even in isolated homes and any small dwellings present in such areas.

The sustainable exploitation of oil plants typical of the Amazon Forest is also a promising way for the use of biofuels and biomass for the production of biodiesel, oils, alcohol (ethanol), and gas (from the fermentation of plants and organic waste), because most of which are kernels and husks arising from the processing of fruit from these trees, unfit for human or animal consumption.

The barrier to implementation of that technology is the fact that the need for the implantation of processing mills for the obtaining of biofuels in remote communities, where access is only by boat (with reference to satellite communities of the city), in order to reduce the necessary logistics for obtaining the raw material, but mainly for the distribution of processed fuel. The same difficulty found in the distribution to the cities of the natural gas produced in the Urucú River basin, where only will be attended the main communities of cities that are along the way of the gas pipeline Urucú-Coari-Manaus.

Although the use of natural gas is not a totally clean way to generate electric energy, its implantation replacing diesel oil and heavy oil causes a decrease of approximately 30% of CO_2 emissions in the atmosphere, reduces considerably the emission of sulfur, decreasing the incidence of acid rain attacking the fauna and flora and causing financial losses and diseases to humans.

Thus, the study of energy use in the region of the Amazon Forest has many fronts which must be adequately balanced for effective distribution of electricity that promotes sustainable development of the region. For this balance, a detailed study of each source must be done, with a focus in the climatological, geographical, environmental and social paradigms of the region of the Amazon forest that must be respected and used in order to maximize their potential. A sample of this potential is on the characteristic of the high index of humidity of the region can be used for electricity generation by means of gas-solid interface as presented in [34].

Similarly, the use of fuel cells, from the hydrogen generated by water hydrolysis presents itself as a good alternative for complementation of electricity produced by diesel generators or natural gas. The reason is that the use of photovoltaic panels used for the production of hydrogen could supply from 30% to 40% of the demand for fossil fuels, mainly in the period of receding rivers in the Amazon region.

With certainty the solution to the provision of electricity for the inland population will require a multiple and integrated approach of the various types of resources available, being necessary the involvement of federal, state and municipal governments, as well as the society itself, in this huge venture.

To solve this question of electric supply in the region of the Amazon Forest is not only to solve a problem of supply of electricity for more than one million people, but primarily to promote the socio-economic development of the region, ensuring that these initiatives promote the sustainability of the communities, and the preservation of their own environmental assets of the forest. To neglect this situation is to relegate such people to the obscurity, the underdevelopment and the lack of services and products from the use and benefits of electricity.

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